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A survey of the facilities and research programme of the Radar Research Station

by

W.G. Harper

(Meteorological Office)

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1. Introduction

A survey of the facilities and research programme of the Radar Research Station at East Hill is particularly desirable at the present time for two reasons, first that tentative proposals for building development in the area suggest that East Hill will become untenable as a radar site within three to four years, and second that the existing 10-cm radar equipment, which has been in continuous operation for almost 10 years, cannot be expected to have a further useful working life of more than a few years, and would probably not stand transfer to a new site.

2. Brief history

The importance of radar in meteorological research was realised during the Second World War, and at its conclusion the easing of defence requirements enabled the Meteorological Office to take over the R.A.F. radar station at East Hill (2 miles northeast of the Central Forecasting Office, Dunstable) for meteorological research. A small staff was appointed and radar records commenced in 1947.

3. Present equipment and site

3.1. Equipment in use since 1947

The equipment taken over from the R.A.F. in 1947 is Radar A.M.E.S. type 21 Mk 1. It was designed for the detection and tracking of aircraft, but gives good responses from precipitation. Of high power and operating on 10-cm wavelength, it comprises two separate equipments, one designed for plan-position display, the other for range-height display. Essential characteristics of this equipment are given below:-

/3.1.1.

3.1.1. 10-cm plan-position radar (type 14)

(a) Characteristics

Peak power (nominal)	500 kw
Beam widths to half-power points	$1\frac{1}{4}^\circ$ in horizontal
	6° in vertical
Pulse length	1.9 μ sec
Pulse recurrence frequency	500 sec^{-1}
Rotation frequency up to	4 rev min^{-1}
Display ranges	30, 60, 120 mi
Cathode ray tube	12 in. diam.

(b) The aerial is adjustable in elevation from 0° to 9°, but adjustment involves heavy manual labour, and the aerial is normally rotated with the centre of the beam 2° above the horizontal. This is a compromise relating to the obstructions in the vicinity of East Hill, and to the average height of the melting level of precipitation, for this usually gives the strongest echo and the best chance of detection.

(c) An upper aerial of the same horizontal beam width, but 12° wide in the vertical, is inclined $3\frac{1}{2}^\circ$ above the lower aerial. This gives a higher cover, which is of value when working with aircraft in the East Hill area.

(d) Slight modifications have been introduced to improve the performance of the equipment in precipitation, but the basic instrumentation is unchanged. Despite careful maintenance it is deteriorating with age. Its further useful life cannot be put at more than a few years.

3.1.2. 10-cm range-height radar (type 13)

(a) Characteristics

Peak power (nominal)	500 kw
Beam widths to half-power points	$1\frac{1}{2}^\circ$ in vertical
	$7\frac{1}{2}^\circ$ in horizontal
Pulse length	1.9 μsec
Pulse recurrence frequency	500 sec^{-1}
Display ranges	75, 150 mi
Cathode ray tube	12 in. diam.

Sweeps continuously in elevation over the arc -1° to 20°, covering one complete cycle in 10 sec. Manual control in azimuth from the display panel.

(b) An alternative range-amplitude display (A-scope) is available on the type 13, but signal generator test equipment is not held, and neither the type 13 nor the type 14 can be calibrated absolutely.

(c) The remarks of 3.1.1.(d) apply equally to this equipment, and like the type 14 its further useful life cannot be put at more than a few years.

3.2. Equipment in use since 1949

3.2.1. 3-cm range-height radar (type AN/TPS-10)

(a) Characteristics

Peak power (nominal)	65 kw
Beam widths to half-power points	0.7° in vertical
	2° in horizontal
Pulse length	1 μsec
Pulse recurrence frequency	1000 sec^{-1}
Display range	60 mi
Cathode ray tube	12 in. diam.

/Sweeps

Sweeps continuously in elevation over the arc -2° to 22°, covering one complete cycle in 1 sec. Manual control in azimuth from the display panel.

(b) A separate range-amplitude display is available, and with signal generator test set TS-263 echo intensities can be calibrated absolutely. This is a valuable feature of this equipment. More complete details have been given in M.R.P. 984.

(c) This radar is of American construction and is on indefinite loan to us from the Radar Research Establishment, Great Malvern.

(d) Replacements for electrical components are generally available, but spares are not held for all mechanical components and it is doubtful if some could be obtained. Thus breakdown of mechanical components will probably determine the life of this equipment.

(e) Spare equipment is at present mounted as a fixed vertical-looking aerial on amplitude display.

3.3. Equipment in use since 1953

3.3.1. 10-cm precision radar (type GL3)

(a) This type of radar is in general use in the Meteorological Office for upper wind measurement. It uses a split beam technique for the accurate measurement of azimuth and elevation of discrete targets such as corner reflectors, aircraft or "window" packets, and achieves considerable accuracy in range measurement by using a short pulse length, but is not suitable for use on extended diffuse targets such as precipitation echoes.

(b) Characteristics

Peak power (nominal)	250 kw
Beam width to half-power points	6° conical
Pulse length	1 μ sec
Pulse recurrence frequency	420 sec^{-1}

Effective range up to 50 miles on a good corner reflector. Control is manual on range, elevation and azimuth, covering elevations 0° to 90° on any azimuth.

(c) Accuracy is about 20 yd in range, and 0.1° in elevation and azimuth on a good corner reflector.

3.4. Auxiliary equipment

3.4.1. Radio telephone (VHF)

Comprises duplicate transmitters BC-640C and receivers R1392D working on fixed frequency 105.48 Mc/s. Essential in aircraft co-operation flights.

3.4.2. C.R.D.F. equipment Mk 2

This equipment has been replaced at the stations of the "Sferics" network by the Mk 3 C.R.D.F., and the Mk 2 set formerly in use at Irvinestown has been acquired for studies of occurrence of lightning in relation to growth of cumulonimbus (see 5.2).

3.4.3. Camera obscura. For tracking smoke puffs fired from aircraft (see 5.5).

3.5. Present site

As propagation at radar wavelengths is essentially straight line propagation, modified only by refraction, an important range limitation is

set by the curvature of the earth. Because of this curvature much of the distant precipitation to be studied is at very low elevations, and in meteorological research by radar a very open site is essential.

East Hill is a good site, but is not ideal. Its main limitations are as follows:-

(a) The escarpment of the Chilterns 2 miles SSE rises 250 ft above the station and presents a maximum obstruction of 1.3° in elevation. This means that all precipitation below 4,000 ft at a range of 30 miles, and below 9,000 ft at 60 miles in this sector is hidden from radar view.

(b) Isolated trees within $\frac{1}{2}$ mile of the station cast significant shadows when observing at low elevations on westerly bearings.

(c) East Hill is in an airway, and is just inside the London Air Traffic Control Area. This makes co-operation with aircraft difficult, and with tightening aircraft control regulations has latterly prevented all flight in cloud in the East Hill area. There are restrictions also on visual flight when cloud is present.

4. Outline of work already done

A list of papers originating from East Hill is given in the Appendix.

The unique properties of the radar in demonstrating accurately the vertical and horizontal extent of precipitation occurring simultaneously over a wide area have been used in a number of studies. In particular considerable effort has been devoted to the study of shower and thunderstorm clouds. It has been possible to direct instrumented aircraft into the most active parts of such clouds and important relationships have been established between the radar echo characteristics of the cloud and the turbulence encountered within the cloud. This has made it possible to assert with confidence that an aircraft fitted with radar would be able, by avoiding the echoing volumes of cloud, to avoid the most severe turbulence encountered in these clouds. Airborne radar for this purpose is now coming increasingly into use while ground radar is also being used with success for giving advice to pilots taking-off or about to land. Detailed examination of the records from the instrumented aircraft have also thrown light on the distribution and magnitude of the vertical currents within the clouds.

Information on the horizontal extent of cumulonimbus clouds (from P.P.I. records and controlled aircraft flights) has also been obtained and used in an assessment of the distances over which aircraft may be exposed to severe icing. This has proved of value in the design of aircraft de-icing systems.

The development of new thunderstorm cells in relation to existing ones was the subject of one study and further work is desirable, while observations of lightning discharges on radar throw some light on the mechanism of the generation of electric charge within thunderstorms.

The examination of the vertical extent of weather echoes gave the first positive information of the heights at which large precipitation particles exist and led to conclusions regarding the different methods of formation of raindrops in layer and convective clouds.

The fact that radar echoes can also be received from volumes of the atmosphere containing large gradients of refractive index has been demonstrated and provided an explanation of some unusual echoes ("angels") which have been troublesome to aircraft controllers.

Investigation of the movement of showers and precipitation belts demonstrated the feasibility of short period forecasts of precipitation using radar and the results are now being applied in the London area.

/The

The variation with height of rainfall has also been studied and is of value in assessing the contribution of coalescence between raindrops to the rate of rainfall. Information on the variation of rainfall with height is also required in rain erosion problems.

Drop-size distributions at different rainfall rates have been measured and used to deduce an empirical relationship between radar echo intensity and rate of rainfall, but an experimental check of the relationship by measuring echo intensity above recording raingauges encountered many difficulties (see, however, Section 5(i) below).

5. Problems to which it is proposed to devote priority attention in the next year or two using existing equipment

(i) The relation between radar echo intensity and rate of rainfall

Empirical relationships between echo intensity and rate of rainfall have been established in various parts of the world on the basis of mean drop-size distributions in rainfall determined by various techniques. A direct check of this relationship by measuring rainfall intensity at the same time as echo intensity has been attempted here in the past but has failed principally because of the lack of knowledge of how typical rainfall measured at one raingauge was of the whole large volume from which the radar echo was received. The establishment of a close network of recording raingauges at Cardington only 13 miles away and the ability to make intensity measurements with the narrow beam-width 3-cm equipment above this network makes possible a new assessment. A successful outcome of this experiment would enable an assessment of the potentialities of radar for measuring rainfall intensities over wide and small areas and may have application, for example, to the vexed question of measuring rainfall at sea.

(ii) Movement of belts of precipitation

Successive P.P.I. pictures of belts of precipitation associated with cold fronts, occlusions and troughs enable a very accurate determination of the speed of movement and orientation of these belts. The accuracy of measurement is greatly in excess of that which can be achieved using synoptic charts. Correlating the movements so determined with the upper winds measured at neighbouring radiosonde stations will determine the level governing the movement of these belts. A large amount of work has already been done on these lines and the results so far are encouraging. A high correlation, for example, between the movement of precipitation belts and the component of the wind at 700 mb normal to the belt would be of great forecasting significance.

(iii) Movement and life of showers and thunderstorms, development of new thunderstorm cells in relation to existing ones. The pattern of shower activity and its relation to synoptic developments

Only radar can give an accurate picture of the distribution, movement, development and decay of showers and thunderstorms.

It is common experience to find that on occasions when occasional showers are forecast over a wide area the actual occurrence of showers is by no means as random as the forecast implies. There is usually some order in the development and occurrence of showers although the reasons may be obscure. Any advance in the ability to forecast the occurrence of showers at a particular place would be welcomed. Similarly for thunderstorms.

Radar is also coming into use at aerodromes for the guidance of pilots and controllers in the avoidance of turbulent cloud at the critical times of take-off and landing. If a thunderstorm is near to an aerodrome it is important to know at what place relative to this storm new cells are most likely to develop.

Theodolite and radar studies of convective cloud should give a measurement of the location of the first precipitation within a cloud in relation to the total vertical extent and life of the cloud. This should throw light on the detailed mechanism and growth of shower clouds.

(iv) Short period forecasting

This involves examination of the reliability of short period forecasts of precipitation made by extrapolation of the movements of the radar echoes associated with precipitation. (At present being investigated by M.O.21 on the basis of information supplied from East Hill sets and from the Decca Type 41 set on Victory House).

6. Other problems to which attention can be given as circumstances permit

Brief outlines only of these problems are given.

(i) Measurements of the variability of wind with time and distance. Measurement of entrainment into cumulus cloud. Using "window" and precision G.L.III radar.

(ii) The development of lightning in cumulonimbus clouds. The stage of development of the cloud when lightning first occurs. Using C.R.D.F. and radar as lightning indicator. May throw light on the mechanism of generation of charge.

(iii) "Angel" echoes. These have proved troublesome at times on aircraft control radars and it would be valuable to know more precisely the reasons why, and the conditions under which, they occur.

(iv) Variation of rainfall in frontal precipitation, possible orographic effects. By relative intensity measurements on P.P.I. presentations. Cross-sections through fronts using synoptic data would be of value here.

(v) Variation in the "bright band" height as a guide to variation of melting level in precipitation.

(vi) Growth of drops and snowflakes during their fall. By measurements of signal intensity changes in the vertical.

(vii) Radar watch on "seeding" experiments, either small-scale by M.R.F. or large-scale by Porton.

7. New equipment and site

It is necessary to make some assumptions as to the probable future equipment of the Radar Research Station and of its future site insofar as they affect the future research programme. For this reason some of the more important factors relating to equipment operating on the various wavelengths are given below:-

7.1. Millimetric radar

(a) Research at millimetric wavelengths is included in the Meteorological Research Committee's programme, and it is hoped that progress will soon be possible on this item. Estimates for the construction of an 8.6 mm set have recently been asked for from various manufacturers.

(b) The choice of 8.6 mm wavelength is determined by the position of the absorption bands due to water vapour and atmospheric oxygen. Those for water vapour fall at 13.5 and 1.6 mm, but of equal importance are those due to oxygen at 5.0 and 2.5 mm. Minimum attenuation of about 0.11 db mi^{-1} occurs at about 8.6 mm. A secondary minimum (at 3.75 mm) of about 0.26 db mi^{-1}

/between

between the oxygen absorption bands presents interesting possibilities, but the technical problems of contructing equipment at this short wavelength are very great.

(c) The reduction to millimetric wavelengths makes possible the detection of clouds containing large droplets or ice crystals, as distinct from precipitation particles of raindrop size, but attenuation limits the range of observation to about 10 mi. For this reason the main recording equipment should be vertical-looking, but through-the-zenith scanning would be a valuable additional feature.

(d) Lines of possible research with 8.6-mm radar are suggested in Section 8.

7.2. Centimetric radar

Centimetric radar is essential if studies of precipitation processes are to be continued. The range of possible wavelengths is from 3 to 10 cm, for beyond 10 cm the cost of equipment increases rapidly due to the very large aerials and the very heavy rotation gear involved. The possible wavelengths in the range 3 to 10 cm are discussed below:-

7.2.1. 3-cm radar

(a) No high-power all-purpose British 3-cm radar suitable for weather radar research is on the market, but a specially designed set has been in use for about two years in America, the AN/CPS-9, details of which have been published. It is of exceptionally high power for a 3-cm radar, with a peak transmitted power of 250 kw, and has a 1° conical beam. This permits good discrimination of weather echoes to considerable ranges. It can be rotated to give a plan-position display or scanned to give a range-height display, and can be switched from one type of rotation to the other in a few seconds. It has complete calibration equipment, a separate range-amplitude display, and special features such as an off-centre plan-position display. It seems to be ideally suited for meteorological research. The present cost of the CPS-9 is understood to be about $180,000 (£65,000). It is unlikely that a comparable British set could be designed and built for less, because the American cost is based on quantity production. (It is understood that three CPS-9s are to be installed in Europe by the U.S.A.F., including one at Sculthorpe in Norfolk.)

(b) Rain attenuation is more serious on 3 cm than on 10 cm, but this is balanced by the improved discrimination given by the narrower beam of the 3-cm equipment.

(c) An important consideration may be that aircraft are more difficult to detect on 3 cm than on 10 cm, and are easily lost from a narrow beam. This would hamper co-operation with the Meteorological Research Flight.

7.2.2. 6-cm radar

Proposals for using 6-cm radar as the best compromise between 3 and 10 cm have received much publicity, but it must be stressed that this is for airborne radar, where aerial size is strictly limited. 6-cm equipment has no merit over 10-cm equipment when aerial size is not prohibitive.

7.2.3. 10-cm radar

(a) This wavelength has been proved to be well-suited to both detection of precipitation and to accurate control of aircraft. It is probably the ideal for precipitation studies in co-operation with aircraft.

(b) Rain attenuation at 10 cm is negligible.

/(c)

(c) Equipment may be available from R.A.F. sources at considerably less cost than a specially designed 3-cm radar, though installation costs would be high. It would be more up-to-date than the 10-cm equipment now in use at East Hill, but like it would comprise separate plan-position and range-height radars. This is especially valuable when rapid development is taking place or when time-lapse photography of the displays is necessary. Separate sets also act as a valuable performance check on each other. One is not always conscious of loss of sensitivity on a single set.

(d) Some types of echo, e.g. layer-type "angel" echoes, and some faint echoes apparently from cumulus clouds, which have not by any means been completely investigated, are detectable on 10-cm radar but not on comparable 3-cm radar.

7.3. These factors suggest that the most valuable solution would be the acquisition of new 10-cm radar equipment, to be supplemented by our existing 3-cm range-height radar, which can be expected to have some further years of useful life, and by an 8-mm radar for cloud studies.

If new 10-cm equipment cannot be obtained, every effort must be made to transfer the present 10-cm sets to a new site and to prolong their life as much as possible by rigorous maintenance.

7.4. New site

The requirements of the research programme, involving co-operation with aircraft, and a low-level unobstructed radar beam for precipitation studies, severely limit the choice of a new site. It is clearly desirable that it should improve on the old if new and expensive radar equipment is to be acquired.

The most important present restriction is that on flying in cloudy conditions. When this involves short runs in cloud, with frequent changes of altitude, as is usually the case in this type of co-operation, the flights can at present only be made under full safety control within the radar coverage area of Farnborough. This precludes all such investigations with East Hill.

It is desirable that a new radar station should have the following features:-

(a) a very open site with unobstructed horizon

(b) a site within 40 miles either of Farnborough or of an area prohibited to other aircraft

(c) a site clear of airways, aircraft control zones and flight restrictions

(d) close contact with other research departments of the Meteorological Office.

The possibility of siting at Farborough itself is excluded because of the multiplicity of existing radars there, and the severe restrictions that the airfield controller would have to place on the use of meteorological research radar in bad weather conditions. From most other aspects such an amalgamation would be wholly beneficial.

A site near Basingstoke would qualify under (b) and (c). The sector clear of airways is here some 25 miles wide, but is still within 20 miles of Farnborough, and roughly 25 miles from Bracknell.

It is doubtful whether an area prohibited to other aircraft could be allocated to the Meteorological Research Flight. If one were it would

/probably

probably be in a remote part of Britain with serious objections under (d) and possibly inconveniently far from Farnborough. However, the question is still under examination.

Some compromise on requirements is necessary, and a site at Bracknell has much claim to consideration. It would have ideal contacts under (d). It is about 10 miles north of Farnborough, and could work closely with controlled aircraft over and to the west of Farnborough in a restricted sector. The principal difficulty is that every change of course of the aircraft would have to be agreed, over radio-telephone, between three authorities - the Controller, the aircraft, and the meteorological radar station. Moreover Bracknell lies within the London Control Zone and within the Western Airway leading out of London, and is only 14 miles WSW of London Airport itself. The possibility of obtaining an unobstructed site in the Bracknell area is nevertheless being explored.

8. Investigations using 8-mm radar

(a) Basic survey of frequency of detection of various cloud types, and determination of factors which affect detection. Assessment of 8-mm radar as a cloud base and top indicator. It will be important to know in which clouds echo bases are a reliable guide to cloud base, and those in which the droplet distributions at cloud base are not detectable. Cloud photography and possibly a zenith cloud camera might be used with advantage, with a cloud searchlight for cloud-base measurement. Independent measurement of cloud tops is essential and no doubt M.R.F. could assist in this.

(b) Studies of the mechanism of development, maintenance and decay of cloud systems. It should be particularly useful in the case of non precipitating cloud, but the simultaneous study of precipitating clouds with 8-mm and centimetric radar should also yield results of very great interest.

(c) Interpretation of measured signal intensities in terms of drop-size distribution, preferably with simultaneous cloud-droplet sampling by M.R.F. The distribution of water particles and ice crystals in clouds and its relation to growth processes.

(d) 8-mm radar can be expected to make a valuable contribution to some of the studies already outlined, for example

6(iv) Frontal cross-section studies

5(iii) Early stages of cumulus growth up to the onset of precipitation

6(iii) "Angels" and other unexplained echoes on 3 and 10 cm may be more easily resolvable at 8 mm.

9. Conclusions

Useful research can be undertaken from the existing radar records and with the present and proposed radar equipment. It is suggested that while the Radar Research Station remains at East Hill, probably a period of three years, and while in-cloud flying in the East Hill area is restricted, special attention should be paid to the problems outlined in Section 5.

The research programme after this can be only tentative, but on the assumptions that a good site can be found at Bracknell, that high-power 10-cm equipment will be available, and that an 8-mm radar will be acquired, it is suggested that emphasis should be placed on (a) 8-mm radar studies, and (b) cloud and precipitation studies in co-operation with M.R.F.

10. Reference

Ryde, J.W. The attenuation and radar echoes produced at centimetre wavelengths by various meteorological phenomena. Meteorological factors in radio-wave propagation. Phys. Soc. and R. Met. Soc., London, 1946.

Appendix

Scientific papers originating from East Hill

A. Meteorological Research Papers

J.M.R.P. 99. Relation between radar echo intensity and rate of rainfall.
M.R.P. 453. Size distribution of raindrops.
M.R.P. 458. Heights and temperatures at the tops of radar echoes associated with various cloud systems.
M.R.P. 482. Detection of icing conditions by radar.
M.R.P. 484. Relation between radar echoes from cumulus and cumulonimbus clouds and the turbulence within those clouds, Pt. 1.
M.R.P. 535. Horizontal dimensions of cumulonimbus clouds at various heights.
M.R.P. 564. Distance over which an aircraft flying on a constant heading may experience severe icing in convective cloud conditions.
M.R.P. 593. Relation between radar echoes from cumulus and cumulonimbus clouds and the turbulence within those clouds, Pt. 2.
M.R.P. 613. Thunderstorms of 5th June, 1950 as seen by radar.
M.R.P. 683. Aircraft observations of radar-reflecting particles above the freezing level.
M.R.P. 741. Radar echoes from atmospheric inhomogeneities.
M.R.P. 784. Observations of smoke puffs at heights up to 40,000 ft.
M.R.P. 820. Five flights through a thunderstorm belt.
M.R.P. 984. Variation with height of rainfall below the melting level.

B. Other papers and reports

(a) Radar weather echoes, Pts. I-IV. Met. Mag., Apr.-July, 1950.

(b) Thunderstorm tracks by radar. Weather, June, 1950.

(c) Turbulence in relation to the radar echoes from cumulonimbus cloud. Proc. Third Radar Weather Conf., McGill, 1952.

(d) Radar echoes from precipitation. Mar. Obs., Jan., 1954.

(e) Radar echoes from lightning. Q.J., 80, 1954, 579.

(f) Radar echoes from and turbulence within cumulus and cumulonimbus clouds. Prof. Note No. 109, 1954.

(g) Weather radar in research and operations. Met. Mag., Feb., 1955.

Note. Where a paper appeared as an M.R.P. and was later published in another journal only the M.R.P. entry is listed.